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COMPARISON OF UNIVAC WITH IBM 701

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FOREWORD

A few words of caution to the reader:

Large-scale general purpose digital computers are extremely complicated devices. They achieve their goal of applicability to a broad range of problems only as a result of innumerable compromises in design. Any attempt to compare computers of this kind runs head-on into the fact that a characteristic which makes a specific design particularly useful in one problem may hamper its effectiveness in another; and inevitably, in any complicated scientific problem, the variety of favorable and unfavorable characteristics which affect overall performance is so great that it becomes practically impossible in any brief study to reach any thoroughly reliable conclusions. This difficulty is enhanced in our study by the fact that both machines function well and have proved their usefulness in many problems.

On the other hand, it seems desirable in order to provide guidance for those with little or no experience with large-scale computers to state conclusions in a simple and clear-cut way, even at some expense in accuracy. Accordingly, the reader must beware of treating the conclusions as definitive. In most cases they are no more than broad generalizations which may be invalid for specific classes of applications.

It should be pointed out that since its inception about a year ago, our Facility has been using a Univac

which was purchased by the Atomic Energy Commission, and we are, therefore, considerably more familiar with it than with the IBM 701. However, we have attempted to carry out the comparison in a completely objective manner.

It is important to note that we have confined our attention to those aspects of the machines which are relevant to their use at a computing service center. If one were to consider purchase or rental of a machine, additional considerations would play an important role.

We wish to thank both Remington Rand and International Business Machines for their courtesy and assistance with our study.

E. Bromberg

COMPARISON OF UNIVAC WITH IBM 701

Roy Goldfinger

Section I - Introduction

The purpose of this report is to compare the two most commonly available large-scale high-speed digital computers, the Remington Rand Univac and the IBM 701, from the point of view of a customer at a commercially operated computing center which uses one or the other of these machines. This study was suggested by the Atomic Energy Commission in order to be able to advise those of its contractors who may have occasion to require computing assistance. Since such a customer is not involved in the engineering activities associated with operation and maintenance of the computer, and since hourly charges are generally based on useful operating time, engineering considerations, as such, are not discussed here. The emphasis is, rather, on the time and effort required to prepare a problem for the machine, to check the correctness of these preparations, and to run the problem off.

No simple conclusions can be reached marking either of the computers as generally superior. The designs of the machines are sound in both cases, but they differ significantly in many respects. The effect is to make each machine better suited for some classes of problems and worse for others.

The Univac is characterized by a comparatively fast, highly efficient input-output system, but by slow computing speed and limited internal memory capacity of the mercury acoustic delay type. It possesses an elaborate system of internal checks which reduces the need for programmed checks on the computation. For several reasons which will be developed later, it is an easy machine for which to program and on which to debug.

The 701 has high computing speed and a large internal memory, using both electrostatic tubes and a magnetic drum. It employs a pure binary representation of data, the advantages of which are mixed. The machine does not possess many built-in checking procedures and the input-output systems are somewhat cumbersome; both of these characteristics tend to detract from the advantages of high speed and large memory.

The Univac therefore appears better suited to problems which are complex in their coding, and require a lot of tape movement, but not very much repetitive calculation; whereas the IBM 701 is the better choice for longer-running problems which are highly iterative, easily checked, and do not require much input of data in the course of running the problem.

Three major areas of interest to the prospective user of either machine are: 1) operational provisions, 2) input-output facilities, and 3) computing capacity and speed. In the following sections, the two machines are described and their relative advantages are examined.

The operational provisions which are described in the first section include such elements as the instruction codes, the logical design, and the facilities for debugging. In general, these affect the preliminaries to the actual running of the problem on a "production" basis to obtain the desired numerical results. Accepting as a point of departure the termination of the mathematical analysis in which the problem has been cast into a form acceptable for numerical computation, this phase encompasses the scaling of numbers with reference to the particular machine to be used, the preparation of flow diagrams and coding, the conversion of instructions and numerical data to the language of the machine, and finally, the use of the machine to check the validity of the coding by making trial runs.

The section on "input-output facilities" will compare the two machines on the basis of the procedures required to enter data and extract results and the speed with which each machine can perform these functions.

Finally, under computing capacity and speed fall those considerations which pertain to actual internal computation after the problem has been checked and the data fed in.

One generally assumes that the bulk of the machine hours consumed in a problem will fall into the last area; however, if a great deal of known data is to be processed the input-output category may account for a sizable amount of the machine time. Programming time is usually a matter of man-hours rather than machine hours; but if debugging

is difficult it is even possible for debugging time to equal or exceed production time on the machine.

Shortcomings of a machine in any of these three major areas will increase the cost of doing a problem. The actual distribution of machine time among preparation and debugging, input-output, and actual computation will depend upon the particular problem and the way in which it has been prepared. Any one of the three may, on occasion, take the major share of the time. In comparing the two computers, it seems likely that the Univac is preferable in the first two categories and the IBM 701 in the third.

Section II - Operational Provisions

This section deals with the instruction codes of the two computers, their logical design -- in particular, the checking features and the numerical radix -- and the facilities for debugging. The Univac seems to have a clear advantage with regard to checking and debugging. In view of the amount of time which may be spent in debugging, this advantage may be significant.

A. Instruction Code: The list of instructions or orders which specify operations on the IBM 701 and the Univac are quite similar. Each machine possesses several orders which the other lacks but could use to advantage. These are of such a nature that they accomplish in a single order an operation for which the other machine requires several orders.

If extensive use is made of sub-routine programming, the Univac provides greater flexibility and conservation of memory space in the use of the "R" order for establishing return paths from sub-routines. Four instructions are required by the 701 to accomplish the same thing. Since the use of sub-routine programming is increasingly useful in larger, more complex problems, the saving in memory space in the Univac is appreciable.

The 701, on the other hand, incorporates direct (single instruction) means for the handling of double-precision numerical quantities. Double-precision division is done on the 701 by storing a 71 bit (20 decimal digit) dividend in two registers and giving a single divide order

which operates on the full dividend. After multiplication it is possible to shift and round numbers by giving orders which effectively link the accumulator and multiplier-quotient registers to form a 74 bit register within which numbers may be shifted in either direction and rounded at the least-significant-digit end of the accumulator. A further desirable feature is the ability of the accumulator to preserve overflowed bits in addition or subtraction and to sense significant (non-zero) bits in shifting operations. The latter permits rapid normalization in floating decimal routines which always deal with normalized numbers. Normalizing of numbers on the Univac requires the extraction of digits followed by tests against zero.

Problems which require a large amount of input and output are easier to code for the Univac where a single instruction will suffice to read or write a block of sixty words. While tape is being read or written by the Univac, computation may proceed provided successive read or write operations do not overlap in time. On the IBM machine, where a "copy" instruction must be given for each word to be read in or written out, it is usual practice to employ a standard library sub-routine (K02) which requires a memory space of forty-five words. No useful computation may be performed during the reading or writing period. Actual input-output times will be discussed in Section II of this report. The intention here is to point out the relative ease of coding these operations.

A desirable feature from the standpoint of programming

for the 701 is the arbitrary length of the "unit record" or number of words per block of information on tape. Thus, as many words as desired of a given input or output item may be specified. In view of the more limited memory size of the Univac, the input-output restrictions to integral multiples of sixty words often lead to waste of memory space that in certain problems is already at a premium.

Another area of coding in which the 701 is superior is the access time to stored information. Access time to words stored in the electrostatic memory of the 701 does not depend upon the memory location of the stored word. The conscientious coder preparing a problem for the Univac may well devote a large part of his coding time to minimizing the delay in securing desired words from the ten-word mercury channels. While minimization is never a necessity it is extremely desirable when a saving in machine time is to be effected. Since a careful job of minimization can save running time of a problem in an approximate ratio of 1.5 to 1, the extra effort and programming time involved is usually considered worthwhile in long-running problems, particularly in the highly iterative loops of the coding. Coding for minimum access delay is essentially a trial-and-error procedure based on a thorough understanding of the logic of the Univac and not reducible to a systematic procedure. It can prove to be very time-consuming during code preparation.

B. Checking: The Univac is thoroughly self-checking. Undetected errors due to machine malfunctioning are almost

non-existent in the Univac and for this reason the programmer or coder is free to assume a perfect machine in the preparation of his code. If errors do occur the machine will stop before permitting incorrect numbers or instructions to become a part of the stored memory.

Since the 701 does not possess duplicated computational circuits and applies odd-even checks only in tape reading there is no assurance available as to the accuracy of the results except for programmed checks supplied at the time of preparing the code. The burden of anticipating each possible source of error of which the machine might be capable, and providing means for detecting those errors, can potentially multiply coding time by a sizable factor, particularly on the part of less experienced coders. From this consideration it is apparent that the coding of a problem may be completed more rapidly and easily for the Univac than for the 701. It has become the practice of people using the 701 to rely heavily on tested and proved sub-routines which contain the necessary checking features.

C. Radix Conversion: While programmers using either machine may do their preliminary analysis and scaling in the familiar decimal system, the 701 programmer must eventually have a means for converting his instructions and numerical data to base two, and checking the accuracy of the conversion, as well as converting the numerical results from binary to decimal and checking. Here again, standardized sub-routines are available which perform the actual conversion and checking on the machine, but their use requires special

consideration with a consequent delay in coding and running time.

On the other hand, the use of a machine which stores numbers in pure binary allows for a higher degree of precision in the scaling of quantities, since multiplication by powers of two on the 701 may be accomplished quickly and easily by shifting operations. From the point of view of mathematical analysis this feature of the machine presents a decided advantage where the preservation of significance becomes essential in a scaling problem. The natural choice on the Univac for rapid scaling is to use powers of ten which may not always prove satisfactory.

D. Debugging: Debugging or trouble-shooting of the finished coding prior to putting the problem into production is generally unpredictable time-wise. A code which runs perfectly at first try is seldom written. The amount of debugging time required will generally depend largely on the length and complexity of the coding and the experience of the coder. 701 coding will generally be the longer and more involved in a given problem because of the programmed checks, and greater necessity for use of generalized subroutines.

While at the machine during the debugging session the 701 coder will have to read his partial results and check and modify instructions in the binary system. He will not obtain a typed copy of intermediate results or changes he might make in the coding. The Univac coder can make use of the auxiliary typewriter at the supervisory control to give

him a type-out from any desired part of the memory in decimal and alphabetical notation.

When something is amiss the 701 coder must question the accuracy of the machine as well as his coding whereas the Univac coder has the assurance that the machine would stop itself if it were making errors.

Another advantage the Univac possesses during debugging is the availability of the ten breakpoints on comparisons which permit manual modification of the program, as well as the comma breakpoint to segment his coding. The six sense switches on the 701 panel do not provide for comparable flexibility.

The use of Univac's auxiliary typewriter permits extensive recording of intermediate results for off-the-machine evaluation. These intermediate type-outs are usually desired only for checking purposes and not desired during the final production run. A switch on the Univac panel enables the coder to omit this programmed printing during the later runs without requiring him to alter his coding. If similar printing is required of the 701 it can be deleted from final runs only by removing the printing instructions from the coding. On the other hand, if some of the final printed output is desired during debugging for evaluation of results and as a check on the editing procedure, the advantage lies with the 701 where printing can proceed apace with computation. The Univac requires removal of the output tape to a separate printer which means that the results will not be immediately available.

Another advantage of having a high-speed printer lies

in the rate at which an automonitor routine can function as a tool in debugging. An automonitor routine executes each order in an instruction sequence under control of a master program which examines the effect of the order and informs the programmer of the changes in the content of memory and registers affected by the execution of the order. Since such a program requires much printing, its operating speed is always limited by the printer.

Section III - Input-Output

A. General Description: All input and output on the Univac other than single words is carried out by way of the Uniservos on which reels of magnetic tape are mounted. Instructions and numerical data are transferred under control of the central computer to and from as many as ten Uniservos. Instruction tapes are originally prepared on a separate unit, the Unityper, and result tapes are printed out on paper on a separate unit, the Uniprinter.

The IBM 701 possesses a variety of input-output devices which are linked directly to the computer and require computer time for their operation. The only means for introducing information into the computer originally is by means of punched IBM cards. A card reader, under control of the computer, reads the punched cards and transfers the card images line by line into the electrostatic memory. Data intended to be kept on tape must be transferred from the electrostatic memory to one of the four tape units. Information may also be transferred from tape or cards through the electrostatic memory to one of the four magnetic drums. Output data can be stored on cards by means of a punch which can operate in either binary or decimal code; or else the information can be printed directly by means of a computer-controlled high-speed gang printer.

Usually, an initial processing period must be devoted to preparing tape or cards in binary form for future use in debugging and production. If the input cards have been prepared in decimal form, machine time must be spent in

conversion to binary form.

In terms of machine time, input and output are generally handled more economically on the Univac. However, cards as an input form possess the advantage that they are readily checked for accuracy without the use of the computer, and individual instructions and data are easily removed and replaced in the card deck. The loss in input time with the 701 might well be compensated for in convenience in some problems.

B. Input-Output Time: Since a tape of instructions and data is prepared ahead of time for use in the Univac, the time required to read a program into the Univac represents tape reading time only. Tapes prepared manually on the Unityper have a pulse density of 20 to the inch and are read by the Univac at a rate of sixty words (one block) per 425 milliseconds. Tape prepared by the Univac in the course of computation has a higher pulse density of 100 to the inch and is read or written at a rate of one block per 85 milliseconds. The actual computer time required to initiate a read or write operation is 3.5 milliseconds. Once the operation has been initiated the central computer is free to go on computing while the block is being read or written. If another operation of the same kind (read followed by read, or write followed by write) is called for before the first is completed, the computer will halt until the first is completed.

The 701 reads or writes on tape at a rate of 1250 words per second with an acceleration time of 10 milliseconds.

In comparison with the Univac, sixty words of reading or writing by the 701 require 58 milliseconds from time of initiation to completion. However, there is available some computation time between successive copy instructions (single words), although it might be difficult to make use of that time. When a standard reading or writing routine such as the K02 is employed, the between-copy time is not available for computation. Thus, properly spaced Univac tape movements consume only 3.5 milliseconds compared with 58 milliseconds on the 701 for blocks of comparable length.

The 701 card reader operates at a rate of 150 cards per minute, the punch at 100 cards per minute, and the printer at 150 lines, each containing up to 72 characters, per minute.

It is now standard practice on the IBM computer to write programs in the decimal system using relative address coding. A routine reads the decimally-punched cards, converts to binary and relocates, checks the conversion and relocation, produces a printed copy of the relocated code in decimal and octal, and punches a deck of binary, absolute-address cards for running the problem. The entire process operates at a rate of one input instruction per second. The final step is to reload the binary deck as a check on readability, correctness of check sums, etc.

C. Concurrent Printing: For immediate access to results in large quantity the 701 is the superior system. It is capable of printing out results concurrently with the running of the problem. The printing time for 900

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ten-digit numbers would approximate one minute whereas the same task would require about fifteen minutes on the Uniprinter associated with the Univac system.

In obtaining edited output with the 701 it is again standard practice to employ a library routine. The writing of a unique printing program for each problem is generally not attempted by the 701 programmer because of the complexities of radix conversion, checking, and processing the word images into a form acceptable to the printer. Thus no useful computation time is generally available during the printing operation. The connotation of the term "concurrent printing" is misleading in this regard. What is meant is the ability of the machine to print results during the course of running the problem, but not concurrently with actual computation. Hence the printing time of one minute for 900 words on the 701 represents one minute of computer time not available for computation. The Univac can process 900 words, and prepare an edited output tape for later printing at an average rate of ten milliseconds per word, or roughly ten seconds including tape time.

D. Editing: The Univac allows for greater flexibility in the variety of output format and labelling of results. Since the IBM programmers rely almost exclusively on standardized printing routines (P04 for computer decimal numbers, and P04a for floating point), in which the number of columns, and number of digits per word are invariable, it is often the case that the results desired must be adapted to fit the routine.

On the Univac the need for standardized printing routines is not at all pressing. Univac editing is a fairly simple matter and usually presents a problem no greater than that facing a human typist preparing columns of figures. The number of columns, digits per column, fixed or floating point representation varied from column to column, and row or column labelling as desired are easily adapted to fit the problem. Thus, as regards computer time only, the Univac can produce more flexible output roughly five or six times as rapidly as can the 701.

Section IV - Computation

This section deals with memory capacity and speed of computation of the two machines. Whenever the need for checking is not serious, the IBM 701 is markedly superior to the Univac.

A. Storage Space: The Univac employs mercury delay lines for internal storage of instructions and numbers. There are 100 delay lines, each containing 10 words of 12 decimal digits or alphabetic characters. The internal memory of the Univac is therefore limited to 1000 words. If a problem cannot be coded and computed within this storage limitation, recourse must be had to the magnetic tape storage as an auxiliary memory device.

Univac tape used as auxiliary storage during the course of a problem augments the accessible memory by 1.2 million words on ten servos. It should be pointed out that the principal problem involved in the use of tape as a storage medium on either machine is the access time to desired information, which may or may not be located at the section of tape currently situated near the magnetic reading head. Thus, it may be necessary to move a considerable length of tape to get to the desired sector. It is sometimes possible to program in a way which minimizes movement of tape by reducing searching and shifting of blocks.

The IBM 701 employs the Williams tube for internal storage of instructions and data. There are 72 cathode ray tubes which can store 2048 words of 36 bits each. (A single word is equivalent to ten and one-third decimal digits.)

This storage is augmented by four magnetic drums which can store a total of 8192 words. In addition, the four tape units can store about one million words. The access time to 701 tape will be somewhat poorer on the average than that of Univac because the larger number of tape units on the latter allows more information to be positioned near the reading heads.

The use of the drum memory of the 701 as a storage device for intermediate results and standby instructions is superior to the use of tape on either machine. Although the reading rate is slower, only 800 words per second, the access time will, in general, be much shorter. The average access time to any word is 40 milliseconds, after which continuous reading of consecutive words proceeds at the 800 per second rate.

It should be emphasized that drum addresses cannot be used interchangeably with electrostatic addresses in the coding. Numbers stored on the drums can be used in computation only after they have been transferred to the electrostatic storage. Also, it should be remembered, checking procedures must be employed in the transfer from the drum to the electrostatic storage to insure the validity of the information. This is usually accomplished by word counts and sums.

B. Access Time to the Internal Memory: By the nature of electrostatic storage the access time to any stored word is always one minor cycle, the time required to perform a one-word transfer from one computer point to another. A

minor cycle in the 701 takes 12 microseconds.

In the Univac to obtain an instruction or data word from the memory requires a variable number of minor cylces ranging from one to ten. This is a consequence of the use of the ten-word mercury line. The Univac minor cycle requires 40.4 microseconds. As mentioned previously, careful coding can minimize the delay time in Univac.

C. Computation Speeds: If the same sequences of computation are prepared for both machines and the running time compared, Univac will require about eight times as long on the average as the 701. It is difficult to be precise in stating the time ratio of the two machines because of the variations due to the nature of the computations themselves, such as the ratio of computation time to control time within the program. For programs which are highly computational and iterative in nature with a minimum of control instructions, the Univac-IBM time ratio is probably higher. Some of the speed advantage possessed by the 701 is offset by the need for programmed checking which, if it takes the form of duplicated computation and comparison, will reduce the ratio almost to four to one. In other situations, such as iterative processes, where errors in one step are corrected by the next, the loss in time will certainly not be as great. A Univac program (the solution of an ordinary differential equation), in which access time was minimized, was compared with similar coding, unchecked, for the 701. The time ratio was 5.03:1. This program required a high control to computation ratio. On the other hand, a single iteration step of a

Newton-Raphson computation for obtaining a square root showed a ratio of 8.06:1. (The presence of the division instruction slows the Univac considerably.)

Section V - Conclusion

The Univac appears to be generally superior as regards ease of debugging, provision of checks, and amount of machine time required for processing of input and output data. On the other hand, the internal memory capacity and computing speed of the IBM 701 are substantially superior to those of the Univac.

Consequently, the IBM is to be preferred where the problems are relatively simple and a great deal of repetitive calculation is needed. The Univac has the advantage when there is a great deal of input and output data to be handled and the problem will require much tape movement and many print-outs.

The Univac will also probably be superior for highly complicated problems which require extensive debugging and checking, if the amount of "production" computation is not very great. As the number of "production" runs increases, the advantage will gradually shift to the IBM 701.

As a practical matter, in view of the soundness and fairly good speed of both computers, it would seem desirable for any computing group to stick to one of the two computers for most purposes in order to acquire skill in the preparation of problems and to reduce the time spent in such preparations. Although the cost of man-hours may not be very great, inexperience with a computer may cause serious delays in obtaining the desired information.

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